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The Engineer and His Pilot Plant

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The physicist, chemist, and biologist study a farm product and discover that something good and useful can be made from it. Using beakers, flasks, filters, stills, and such laboratory equipment, they develop on a small scale a method for making the new product, but before it can be an article of commerce some questions have to be answered: Is there a potential market for it? Is it feasible to make it on a large scale? What sort of factory equipment will be needed? What will it cost?

The chemical engineer undertakes to answer the last three questions. His workshop is the pilot plant. His tools range from buckets and shovels to intricate reproductions of large-scale chemical-processing machinery. With pumps, pipes, meters, and control instruments, he integrates the small-scale units into the equivalent of a small factory, the pilot plant. With them, the chemical engineer usually can find the answers to the three questions.

You might suppose that transferring a laboratory method to a commercial process would be solely one of increasing the scale of operations. It is far more than that, for in the pilot plant there must be answered questions that cannot logically be studied on a laboratory scale and that would be too costly to answer on a factory scale.

For instance, the problem of corrosion. Glass is all right in the laboratory, but it would not be used in factory operation unless less expensive and less fragile materials (such as wood, steel, copper, stainless steel, or Monel metal) could not be used. The chemical engineer must determine the cheapest and most durable material to use, consistent with maintaining quality in the product.

A larger scale of operations may pose another problem—putting heat in or taking it out of the reacting chemicals. In the laboratory one can use a bunsen burner to heat the flask. One can put the flask in a bucket of ice if it gets too hot. In the factory, however, heating may have to be done by electricity, direct firing, or steam. Cooling may have to be done with tap water or a refrigerant. The transfer of large quantities of heat to reaction vessels may entail a problem of design, especially if the materials are viscous or sensitive to heat. The chemical engineer must therefore take economy into consideration and must apply the principles of heat transfer and fluid flow to the design of his equipment. At times he may have to modify the process to make it feasible on a large scale.

A specific example illustrates the pilot-plant stages. Each year thousands of tons of red oil are used to make agents for processing textiles, lubricants, soaps, protective coatings, and other items. Red oil can be considered a crude oleic acid, of which it contains about 70 percent. In the course of research on animal fats and oils at the Eastern Regional Research Laboratory, chemists found a means of producing an oleic acid of 85 to 95 percent purity. They used the same starting materials as in making red oil—inedible animal fats obtained from the slaughterhouses. The cost of the purer product might be higher than that of red oil. In order to find whether there was a potential market for the improved product even at a somewhat higher cost, a market survey was made by the Laboratory's industrial liaison representative. He learned that there was a market for the new product. Chemical engineers then undertook to find out whether its manufacture would be feasible on a large scale, what sort of factory equipment would be required, and what it would cost.

The chemists found that by combining hydrogen with the fats, splitting them into their respective acids, and then chilling them in acetone, they could separate the fats into two fractions—a solid one and a liquid one. The liquid fraction comprised the new, purer oleic acid, dissolved in the acetone. The acetone was removed to give the new product.

In the laboratory the chemists used acetone in a 5-gallon bottle to dissolve the mixture of fatty acids, with which some hydrogen had been combined, and chilled the resulting mixture in a refrigerator. They filtered off on a cold suction filter the crystals that formed, again operating in an improvised refrigerator. Then they distilled the liquid drawn off from the crystals to remove the acetone. The new, purer oleic acid remained.

Obviously, merely to scale up these operations would not be feasible commercially. To carry them out batchwise, as the chemists have to do, would cost too much for labor and would waste refrigeration, because the solutions would be warmed by exposure to air while being handled. Pilot-plant studies were therefore planned to make the process a continuously flowing one. If the dissolving, chilling, and filtering could be done in closed apparatus with the liquids flowing steadily through them, the labor would be reduced to merely watching and adjusting the machinery, and the solutions could easily be kept cold. Continuous operation also makes a more uniform product.

Before designing an integrated unit for continuous operation, the engineers experimented to determine the effect of rate of cooling the acetone solution on the character of the crystals and on the completeness of crystallization. Because the crystals had to be filtered on a continuous filter, it was desirable to have them of such a character that the solvent could be sucked away from them rapidly. The results of that work permitted the engineers to design the pilot-plant unit. When this unit is completed, the partially hydrogenated fatty acids and the acetone will be automatically fed to the crystallizer in the proper proportions.

The crystallizer is a long, stainless-steel tube, surrounded by brine at about 40 degrees below the freezing point of water. As the mixture flows through the tube, crystallization takes place, and scrapers remove the crystals from the walls of the tube. When the materials leave the crystallizing tube, the mixture of crystals and liquid passes over a rotating drum covered with filter cloth. The crystals are continuously scraped off the surface of the drum while the liquid fraction flows from inside the drum. The liquid can then be distilled by a continuous process to remove the acetone, which is returned to the system for reuse. When the operation of the unit has been studied experimentally, we shall be able to answer the questions necessary to translate the process into commercial operation.

BUT BASIC RESEARCH on the development of new processes does not always originate in the laboratory. Some new process or product may wait only on the solution of an engineering problem. Take the case of a process that chemical engineers developed for recovering in concentrated, unaltered form the volatile flavoring constituents of apple juice. It had long been known that by vaporizing 10 percent of the freshly pressed juice all the volatile flavors could be obtained in the distillate. The 10-fold concentration, however, was too low to be of practical use, and the aim was to obtain a highly concentrated essence without losing any of the flavors. The problem was an engineering one. It had two aspects. It entailed the design of an evaporator that would make possible the vaporization of 10 percent of the juice under conditions of time and temperature that would not change the flavor of the stripped juice or the essence. Moreover, some means for concentrating the aromas and collecting them without loss had to be devised. If the vaporization were done under vacuum, the aromas were difficult to capture. It thus became necessary to design an evaporator that at atmospheric pressure would achieve the desired vaporization quickly.

When that was done and the evolved vapors were concentrated in a packed column and the vent gases were scrubbed with chilled essence, the aroma fraction was obtained. Cost estimates were prepared, the basic engineering data and operating procedures were compiled, and recommendations for large-scale operation were published by H. P. Milleville and me. Apple essence is discussed at greater length in the next chapter.

The essences of apples and other fruit are now becoming important articles of commerce. They can be used to give the true flavor of fresh fruit to carbonated beverages, candy, ices, and a host of other fruit products.

But the sequel to that account remains to be told. Chemical engineers have started studies of design and pilot-plant research to find out if they can recapture the appetizing aromas that come out of the kettles in which jam, jellies, and preserves are being made. Such concentrates could be used to improve the flavor of the products made in the kettles or as concentrated essences to improve the flavor of beverages, bakery products, and the like.

The technical feasibility of a new process has to be determined. Cost analyses also are required. Industrial utilization of an agricultural commodity will not eventuate unless there is an actual or potential market for the new product and unless the producer can make a profit on the enterprise. The cost analyses are frequently made at more than one stage. Even in the original laboratory studies it is desirable often to make at least a preliminary estimate to clarify the relationship between value of product and probable cost of production. As pilot-plant investigation progresses, several lines of approach may present themselves. A cost estimate at this stage is frequently used as one criterion in making a choice. Finally, when the process has been proved both technically and economically sound, detailed estimates of costs are prepared for publication, along with the basic engineering data, in order that a potential manufacturer may have all details before he decides whether or not to adopt the process.

THUS the chemical engineer, through pilot-plant research, can predict with reasonable accuracy what a new product will cost. He can recommend the type of equipment to be used in the factory and provide basic engineering data for the design and operation of commercial units. Only in this way can the fullest practical use be made of the laboratory researcher's findings.

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